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TECHNICAL MANUAL

DESIGN OF UNDERGROUND INSTALLATIONS IN ROCK

SPACE LAYOUTS AND EXCAVATION METHODS

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By Order of the Secretary of the Army:

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ENGINEERING AND DESIGN

DESIGN OF UNDERGROUND INSTALLATIONS IN ROCK

SPACE LAYOUTS AND EXCAVATION METHODS

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INTRODUCTION

3-01 PURPOSE AND SCOPE. This manual is one of a series issued for the guidance of engineers in the design of underground installations in rock. It is applicable to all elements of the Corps of Engineers who may be concerned with the design and construction of underground military installations. Criteria are presented herein, and in the related manuals of this series, relative to the protection against weapons of modern warfare afforded by underground installations in rock. The physical and economic factors involved in new construction or the conditioning of existing mines for storage purposes and occupancy are discussed. Guidelines have been included relative to devices and measures that should be taken to meet protective requirements.

3-02 REFERENCES. Manuals - Corps of Engineers - Engineering and Design, containing interrelated subject matter are listed as follows:

DESIGN OF UNDERGROUND INSTALLATIONS IN ROCK

EM 1110-345-431	General Planning Considerations
EM 1110-345-432	Tunnels and Linings
EM 1110-345-433	Space Layouts and Excavation Methods
EM 1110-345-434	Penetration and Explosion Effects (CONFIDENTIAL)
EM 1110-345-435	Protective Features and Utilities

a. References to Material in Other Manuals of This Series. In the text of this manual references are made to paragraphs, figures, equations, and tables in the other manuals of this series in accordance with the number designation as they appear in these manuals. The first part of the designation which precedes either a dash, or a decimal point, identifies a particular manual in the series as shown in the table following.

EM	paragraph	figure	equation	table
1110-345-431	1-	1.	(1.)	1.
1110-345-432	2-	2.	(2.)	2.
1110-345-433	3-	3.	(3.)	3.
1110-345-434	4-	4.	(4.)	4.
1110-345-435	5-	5.	(5.)	5.

b. Bibliography. A bibliography is given at the end of each manual in the series. Items in the bibliography are referenced in the text by numbers inclosed in brackets.

3-03 RESCISSIONS. This manual is a reissue of material presented in an Engineering Manual on Design of Underground Installations in Rock (13 chapters), dated March 1957, prepared for the Corps of Engineers, U. S. Army, by Bureau of Mines, U. S. Department of Interior.

3-04 MANUAL PREPARATION. The manuals of this series were developed through collaboration of a number of organizations. The Corps of Engineers, U. S. Army, initiated the work and outlined the scope of the manuals. Data from the underground explosion test program, underground site surveys, and information gained in the Fort Ritchie and other construction were furnished to the Bureau of Mines, Department of the Interior, who assumed the responsibility of compiling the manuals. They, in turn, contracted for preparation of certain material by organizations having special competance in the various fields covered. The work of preparation was as follows:

EM 1110-345-431 General Planning Considerations. Prepared by Missouri School of Mines and Bureau of Mines, U. S. Department of Interior.

EM 1110-345-432 Tunnels and Linings. Prepared by the Bureau of Mines, U. S. Department of Interior, and the Rensselaer Polytechnic Institute.

EM 1110-345-433 Space Layouts and Excavation Methods. Prepared by E. J. Longyear Company, Minneapolis, Minnesota.

EM 1110-345-434 Penetration and Explosion Effects (CONFIDENTIAL). Engineer Research Associates.

EM 1110-345-435 Protective Features and Utilities. Prepared by Lehigh University; Bureau of Mines, U. S. Department of Interior; and the Corps of Engineers, U. S. Army

3-05 GENERAL. This manual discusses planning of entrances and chambers by considering (1) design as discussed in EM 1110-345-432, (2) types and

requirements of openings, (3) excavation methods and equipment, and (4) time and cost. Considering the difference in the uses which may be made of the excavations, the extraordinary variety of geologic and topographic settings, variations in transportation facilities and circumstances governing construction, it is likely that each project will be unique. Therefore, attention is concentrated on principles rather than on details. There are four ways in which any project may be planned:

(1) By following a prototype, which is simple and efficient where the prototype meets the requirements, where all details of the prototype are understood, and where conditions to be met in the new project are similar to those of the prototype

(2) By determining requirements and conditions, by applying knowledge of similar projects, by conceiving one or more plans to meet requirements within conditions, and by selecting the most appropriate means, and scheduling time and cost

(3) By models or "pilot" installations, which are most useful in the study of processes or other projects which may be reduced in scale without seriously affecting the accuracy of results

(4) By various combinations of (1), (2), and (3).

Because requirements and conditions of work here considered may be almost infinitely varied, because prototypes are few, and because it is difficult to reproduce underground conditions to scale, it is generally necessary to rely strongly on the fundamental steps mentioned under (2). Each undertaking should be studied to determine any requirements peculiar to it.

3-06 PROCEDURES. Planning on a project should be in the hands of engineers having broad experience in underground excavations. Those engineers should work closely with people familiar with the functional use of the project. The general procedure for planning should be (1) determination of conditions at site or sites, (2) determination of requirements for site and installation, (3) planning entrances and space layouts, and (4) estimation of costs and time of construction.

CONFIGURATION OF OPENINGS

3-07 FACTORS. Designed openings are compromises between (1) the most stable section, (2) the requirements imposed by the use to be made of the

opening, (3) the means which may be used for excavation, and (4) the limitations imposed by rock defects. The importance of each of these factors may be greater on one project and less on another, but in all cases a stable section is needed.

3-08 <u>SHAPE.</u> Maximum stress developed in the vicinity of openings is a function of the shape of the opening. The effects of shape on stresses in idealized rock are discussed in paragraphs 2-13, 2-14, and 2-15.

In vertical shafts a circular section is often used because it offers the greatest resistance to pressures from all directions, as discussed in paragraph 3-69. In tunnels in soft ground, stresses in all directions are likely to be equal, and a circular section is common. In rock tunnels a circular section is a rare expedient, but a "horseshoe" section is a common practice and a close approach to a circular section with the advantage of a nearly plane floor.

A flat roof develops tension unless confining stress from the sides is at least moderate. Since the tensile strength of rock is almost always low, this may be critical. An excavator is therefore likely to try to avoid any flat roof section and utilize an elliptical or "flattened arch" roof [19, p 95-100]. However, some rocks with strong, horizontal defects may be impossible to maintain arched. If the roof slab is thick and competent, a flat roof may be stable over large areas (as much as 80 ft width in limestone at Santa Eulalia, Chihuahua, Mexico, and in marlstone at Rifle, Colorado).

Stresses are concentrated at corners; therefore, cross sections without corners or with well-rounded corners should be selected, and the excavation should be so planned and carried out that all irregularities in section are minimized. The most plane walls will result from cutting or boring (so-called mining machines working in soft rock), by following a conspicuous, continuous plane of weakness, or by blasting long holes, as described in paragraphs 3-59d and 3-65c. In any case, outside or "trim" holes should be drilled with no more than the necessary divergence, their burden and charging should be moderate, and they should always be timed to fire after other nearby holes. Most contractors, working to a "B" line beyond which they are not reimbursed for rock removed or for concrete

placed, develop particularly good practice in alignment and firing trim holes.

3-09 SIZE OF OPENINGS. The ultimate safe size (cross section) of any opening is limited by structural defects of the rock, but elongation of an opening of given cross section produces only a minor increase in stress concentration. To obtain the lowest unit costs it is desirable to excavate openings with as large a cross section as will be stable without support. Cost data are given in table 3.1. In planning, it is prudent to choose a

Table 3.1. Average Unit Costs

	Excavation			Concrete Lining			Steel Arches			Lagging (Timber)		
Structure Dimensions	Quantity cu yd/ft	$/cu yd	Total $/ft	Quantity cu yd/ft	$/cu yd	Total $/ft	Quantity lb/ft	$/lb	Total $/ft	fbm/ft	$/fbm	$/ft
Tunnels, ft												
8 x 8 (excavated size with flattened arch)	2.2	35.0	77	0.8	65.0	52	72	0.20	14	28	0.28	8
12 x 12	5.0	24.0	120	1.5	46.0	69	176	0.20	35	38	--	11
15 x 15	7.7	21.5	166	2.0	44.0	88	336	0.20	74	50	--	14
17 x 22	13.0	18.0	234	3.3	41.5	137	714	0.20	143	67	--	19
31 x 22	23.0	16.0	368	5.6	40.0	224	1046	0.20	209	80	--	22
50 x 50	85.5	13.0	1112	16.0	37.0	592	3270	0.20	654	160	--	45
Inclines, ft												
17 x 22 - 12%	13.0	20.0	260	3.3	41.5	137	714	0.20	143	67	0.28	19
17 x 22 - 30%	13.0	27.0	351	3.3	46.0	152	714	0.22	157	67	0.31	21
31 x 22 - 12%	23.0	18.0	414	5.9	40.0	236	1046	0.20	209	80	0.28	22
Shafts, Vertical, ft							Steel Sets					
8 x 18 (outside steel)	6.3	40.0	252	2.0	59.0	118	400	0.28	112	104	0.28	29
10 in. diameter	3.4	45.0	153	1.0	50.0	50	85	0.35	30	---	--	--
Raises, Timbered, ft												
6 x 10	2.2	38.0	84	--	--	---	--	--	---	42	0.30	13
High Chambers (75 to 100 ft high)	--	4.0 to 10.0	--	--	--	---	--	--	---	---	--	--
Without support, total volume 50,000 cu yd or more												

cross section which is, by experience as well as by calculation, believed to be stable, and then to rely on the use of rock bolts or occasional steel arches to support areas where defects may be severe. To gain required area or volume, the length of a chamber may be extended, its height may be increased (unless side pressure is more than moderate), or multiple chambers may be used.

3-10 PILLARS BETWEEN PARALLEL CHAMBERS. Design of pillars to be left between permanent openings should be more conservative than that for mine pillars which are usually of temporary importance. The drastic consequences of pillar failure are sufficient reason for making original plans safe.

A conservative rule of thumb is that pillar thickness between parallel openings should not be less than the width or the height (whichever is greater) of the openings. If pillars show conspicuous defects, their width may exceed that of the openings in a ratio of as much as 60/40.

3-11 TUNNELS AND CHAMBERS. Generally the intersection of two openings is an area of high stress and is usually the weakest part of the underground structure. Careful design of the intersection is necessary to minimize the concentration of stress and provide maximum support to the area of intersection. Large intersecting passageways that introduce a large unsupported area should be avoided.

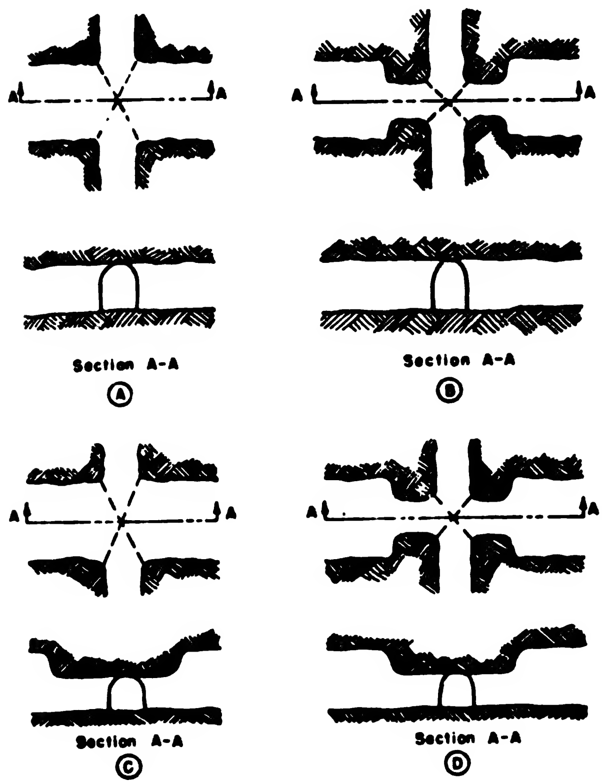


Figure 3.1. Tunnel intersections

To illustrate various methods that may be used to reinforce the rock area in the vicinity of intersections, the following two problems are considered.

(1) The intersection of two arched openings of the same height but of different width forms "groins" and a relatively large, unsupported span. The size of the unsupported span can be reduced by making the larger opening narrower at the intersection as shown in figure 3.1A and B.

(2) The intersection of two arched openings of different heights and different widths forms a "heavy brow" and a large unsupported span. The size of the brow and the

unsupported span can be reduced by making the larger opening narrower at the intersection as shown in figure 3.1C and D.

PRIMARY ENTRANCES

3-12 TYPES OF ENTRANCES. The type of entrances used will depend upon the topography of the site and the requirements of the installation.

a. Horizontal. If possible, entrances will be by horizontal adit, driven substantially level. This recommendation may be limited by the topography and depth of cover required; it may be influenced by the type of rock in which the tunnel is to be situated. The advantages of horizontal development are:

(1) Horizontal entrances are simplest in design and in construction.

(2) Usually support is simpler and less expensive.

(3) Generally, unit excavating costs are lower than for any other form of entrance excavation.

(4) Transportation of material and personnel during and after construction is easy in self-powered vehicles.

(5) Many general contractors are equipped to drive tunnels, while shaft sinking is more specialized work.

(6) If tunnels are driven slightly up-grade, natural drainage may be provided.

b. Slopes. If horizontal entrances are not practicable, entrances may be downward slopes or inclined shafts. The degree of inclination will depend upon requirements of cover and the conditions of topography. Figure 3.2 shows the ranges of slope which may be served by various types of equipment. The advantages of slopes or inclined shafts are:

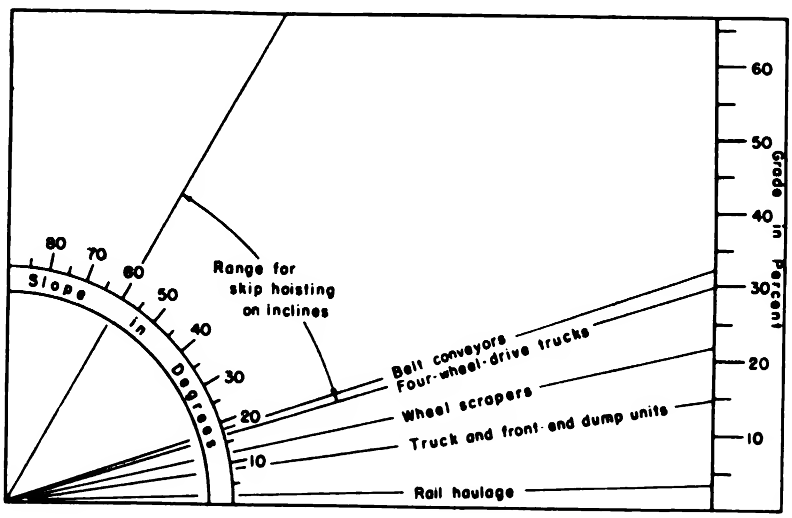


Figure 3.2. Limiting slopes for various types of haulage equipment

(1) As compared with adits, any required cover may be obtained in any location within limits imposed only by cost.

(2) As compared with vertical shafts:

(a) Design may be little more complicated than for tunnel entrances.

(b) Transportation of personnel and material is still possible in self-powered, though perhaps special, vehicles.

(3) As compared with either adit or vertical shafts, entrances may be dispersed within limits imposed only by cost (table 3.1).

c. Vertical Shafts. As an alternative, entrance may be through a vertical shaft. If such an entrance is to be used for transportation of personnel and solid material, a hoisting plant must be provided. The hoist itself may be located underground, but some portion of the plant is necessarily at the surface where it cannot be protected. Also, any damage to the upper portion of the shaft will result in damage to the remainder of the shaft by falling debris. Because of these disadvantages, vertical shafts are likely to be useful mainly as auxiliary openings for disposal of waste gases or for admission of air for ventilation. The principal parts of a hoist plant may not only be contained underground, but the plant itself may be capable of emergency operation without power from the surface by the use of compressed air stored in an underground receiver, the filtered exhaust being used for ventilation. The advantage of vertical shafts is that any required cover may be obtained in low relief areas, in the shortest distance within limits imposed only by cost (table 3.1). Vertical shafts are also an advantage where gases or fluids such as exhaust or ventilating air, water, sewage, and other materials are to be pumped.

d. Combinations. It is obvious that the requirements of most installations are sufficiently complex so that one or more types of entrance may be used. In addition, a single entrance may be a combination of two of the above types. Examples are:

(1) An inclined entrance may be used until sufficient cover is obtained beyond which point it may be connected to the remainder of the installation by a tunnel. This may help to meet requirements of dispersal.

(2) A vertical shaft used for air intake or disposal of exhaust gas may be offset horizontally to confine the effect of surface damage.

(3) A vertical shaft could be approached by dispersed inclines or by tunnels, in which case the entire hoisting plant could be underground where it would be protected and concealed.

3-13 CROSS SECTION. The cross section of entrances will be determined by the following requirements:

(1) Each entrance must be adequate to accommodate the equipment, personnel, utilities (including ventilating air), and traffic required to drive the entrance itself.

(2) One or more entrances must be adequate for equipment, personnel, utilities, and traffic required to construct chambers and to allow reasonably efficient entrance of all building material and equipment to be installed underground.

(3) Alternative entrances must accommodate equipment, personnel, utilities, and traffic needed to operate normally and during emergencies.

Standards of highway and railroad clearance vary. In planning an underground installation in which truck or rail traffic might be important, local standards should be considered. For narrow-gage rail transportation, 8 by 8 ft, 12 by 12 ft, and 15 by 15 ft are common tunnel sizes for single-track railroad or single-lane highway tunnels with minimal walkway on one side, 17 ft wide by 22 ft high may be sufficient; for two-track railroad or two-lane highway tunnels with a minimal walk on each side, tunnel dimensions should be at least 31 ft wide by 22 ft high. It is conceivable that an installation might require entrances for barges or ships.

During construction and in operation, entrance tunnels may be required to carry pipe for water, drainage, and compressed air; power cables; and ducts for ventilating air. Pipe and cable usually do not occupy much space. They are carried on hangers in either of the upper corners of the section or near the spring line. Ducts for ventilation during tunnel driving may be several feet in diameter and are often carried at the center of the arch. Permanent ducts are usually carried in the center of the arch and are usually much larger (see EM 1110-345-435).

Because it is more expensive and awkward to enlarge a completed entrance than to cut it to the larger size during original construction, it is logical to make generous allowance in planning. Exceptions are openings which will, for any reason, have to be closed (as by blast doors or

stoppings to retain fluids) after excavation is complete. These should be driven as small as possible, at least near the location of the stopping or blast door, to decrease expense of the stopping and its installation.

3-14 DUPLICATION AND DISPERSAL. Since it is inconceivable that an entrance could be constructed so stoutly as to withstand a direct hit of a large weapon, all vital entrances must be duplicated. Depending upon the purpose for which the installation is intended, the expense of providing duplicate entrances and the extent of their natural protection, as by cliffs, it may be desirable to plan many entrances. Panero [25, p 10] states that a minimum of three well-separated entrances should be provided for plants of one million square feet of floor space, and that another entrance should be provided for each million additional square feet. This requirement may be regarded as a fair average, but installations housing many people or a particularly vital plant or product would probably be given more.

Entrances should be dispersed. If topography allows, one entrance or group of entrances may be on one side of a hill, and another entrance or group may be on another side. If there is insufficient relief, entrances may be separated by use of slopes. Entry from a number of points may reduce unit costs, and would in most cases reduce time required for construction by providing more working faces.

3-15 ENTRANCE DESIGN. Portal designs and the configuration of entrance tunnels for underground installations require special attention relative to blast effects from nuclear weapons. Portals should be oriented and/or special protection provided to minimize high pressures that might develop from the shock front reflecting from the ground surface area surrounding the entrance of the tunnel. This can be accomplished by constructing a baffle wall with a roof in front of the portal. The cross section of tunnel entrances should be kept to the minimum compatible with the activities of the installation. Where installations are constructed in local hills or plateaus it will be desirable to continue the entrance tunnel straight through with no obstructions that will reflect the shock front in passage. The blast pressure attenuates as it passes down a tunnel; thus, the longer the tunnel entrance the less the design pressures will be for doors that

enter the operational area of the structure. Any abrupt change in the cross section of a tunnel from a small to a large cross section will result in additional attenuation of pressures; therefore, it may be desirable to install a restrictive plug near the portal which would reduce the area to that required for vehicular clearance.

3-16 BLAST DOORS. Optimum door positioning is a major consideration relative to the blast resistance of a protective underground installation. The most favorable location is accomplished by mounting doors flush or slightly indented from the sidewalls of the main entrance tunnels.

Doors through which personnel enter should be in tandem and provided with signal interlocks so that only one can be opened at a time in order that the installation will be protected from blast at all times. Special doors should be designed for rapid closing for operation during alerts. Blast doors for entrance of vehicles are expensive and their number should be kept to a minimum. Tunnel cross sections at door locations should be reduced to as near the door size as is practicable with respect to mining operations. Concrete piers and doorheads can be installed to reduce the door sizes to the minimum acceptable to the operation of the installation.

3-17 DECONTAMINATION. Decontamination facilities in connection with entrances are discussed in EM 1110-345-461.

3-18 PROTECTION OF PORTALS. Portals should be located above any conceivable flood crests, natural or artificial. Landscape scars, roads, and portal structures should be as inconspicuous as possible. Camouflage should be considered. Baffle walls to preclude entrance of reflected blast pressures are shown in figure 3.3.

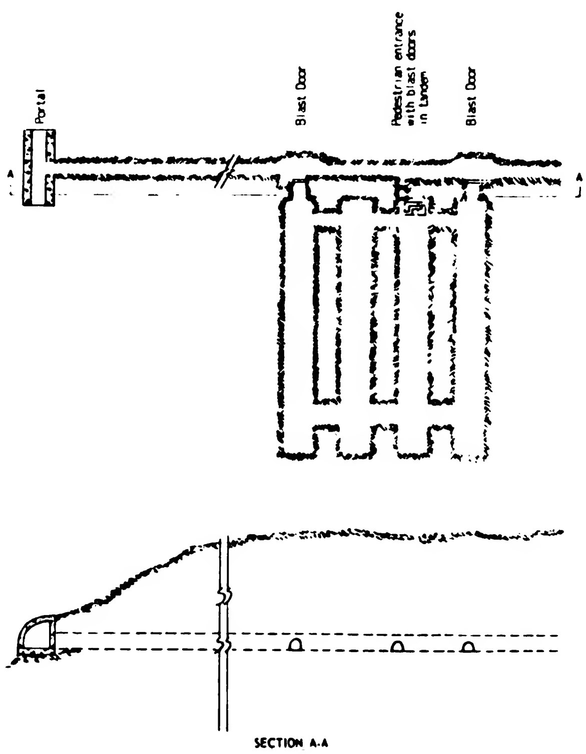


Figure 3.3. Example of entrance layout

3-19 DRAINAGE OF TUNNEL PORTALS. Although the principal portion of a project may be in sound, tight rock substantially free from water, it is likely that fractures and other water-bearing defects will be met near portals. Test drilling should indicate the likelihood of water occurrence, though not necessarily the amount. Even if the drilling and testing are done with care, conclusions formed are likely to be optimistic unless a real understanding of rock permeability and water occurrence is obtained. Drainage is greatly simplified if entrances or drains in or near the walls of entrances slope outward. Beyond a point where water is expected, grade may be reversed if it is desired to put chambers at an elevation below that of the portal.

If one entrance can be made lower than the others, all drainage may be through it. This may require that drainage be brought in pipes or drains to this entrance. If all entrances slope inward, pumping will be necessary.

3-20 PORTAL LOCATION WITH REGARD TO GEOLOGY AND TOPOGRAPHY. The vital installations of a project should be located tentatively before entrances are fixed. The chamber elevation then will indicate the desirable elevations of portals. For the final choice of portals, information from studies of surface geology, topography, and test drilling will be combined with considerations of duplication and dispersal, protection, drainage, transportation, and utilities.

Cost of unlined entrances is about half that of entrances supported with steel and concrete (table 3.1) and driving speed is about double. Unusually bad ground could make these comparisons much worse than indicated by these averages; hence the importance of selecting the soundest rock. Cliffs indicate strong, but not necessarily impermeable, rock. They are also desirable because little opencut work is required to reach a rock face.

3-21 SUPPORT OF PORTALS. All hillside entrances need a reinforced-concrete portal to ward off rock, earth, or water. It should project several feet from natural or graded hill slope. If slopes are steep enough to allow rock to roll, the projection may be 5 to 6 ft. A diversion ditch over the portal is usual.

The support to be provided inside the portal itself depends on the type of rock and its defects. Alternatives are described in paragraphs 3-49 through 3-55 and 3-63 and accompanying references.

3-22 COST AND PROGRESS OF ENTRANCES. Representative contract costs for tunnels and access workings are tabulated in table 3.1, and representative rates of progress are discussed in paragraph 3-37.

SECONDARY OPENINGS

3-23 PURPOSES. Secondary entrances may be used for exhaust air, fresh air, water, power, other utilities or communications, access to isolated chambers, and emergency exits. If time were not important, secondary entrances might be driven to planned locations to check rock conditions. Where completion is urgent, secondary entrances are more likely to be driven simultaneously or after the main entrances. Some secondary entrances such as inclined or vertical shafts may be driven more quickly and cheaply from underground toward the surface.

3-24 TYPES OF SECONDARY ENTRANCES. Secondary entrances may be like main entrances but are usually smaller. Vertical or inclined shafts are at a lesser disadvantage since secondary entrances are unlikely to be used for traffic. If pipe or cable is to be placed in them, or if air is to be forced through them, vertical or inclined entrances may offer the important advantage of reaching their objective in the shortest distance.

For many of the purposes of secondary entrances, boreholes may be ideal. Their cost is usually comparatively modest (table 3.2) and progress good. In sound rock they require no support; where necessary they may be cased effectively at small cost. Fluids or fine solids in suspension may be pumped through unlined holes in tight rock.

All drilling is subject to error in starting alignment and in deviation from line as the hole progresses, but deviation in most types of drilling may be controlled or corrected to some extent.

3-25 LIMITATIONS OF BOREHOLES. Churn-drill holes from 4 in. to approximately 24 in. in diameter are drilled vertically only, through any rock; progress in hard rock may be good if a sufficiently heavy tool string can

Table 3.2. *Average Unit Costs*

	Unit	Cost Dollars
Rock Bolts 3/4- to 1-in. diam (includes scaling and disposal of rock, drilling, placing, and torque test)	Lin ft	1.5 to 4
3-in. Diamond Drill Hole (NX hole, 2-1/8-in. core, uncased, to 600-ft depth) quantity 5000 ft or more	Lin ft	4 to 10
6- to 20-in. Churn Drill Hole (uncased) depth not over 400 ft	Lin ft	0.5 to 1.0 per inch diam
12- to 36-in. Calyx Drill Hole (uncased) depth not over 600 ft	Lin ft	1.0 to 2.0 per inch diam
1.5-in. Grout Holes (uncased diamond drill hole, without core, up to 150 ft deep), volume 10,000 ft or more	Lin ft	1.75 to 3.5
Grouting (volume 10,000 sacks or more)	Sack cement	2.5 to 5
1.5-in. Percussion Drill Holes (uncased, up to 100-ft depth; volume 5000 ft or more)	Lin ft	1.2 to 2
Cement Paint (on rock) including sealing, washing, staging, and cleanup	Sq ft	0.03 to 0.08

be used. For large-diameter holes this is possible only with an exceptionally heavy rig. Efficiency decreases after the first few hundred feet [26, Sec 9, p 41].

Oil field rotary holes from 4-1/4 to 12 in. in diameter are drilled vertically only, though special rigs may allow drilling larger diameters or at angles. Depths of many thousands of feet may be reached, but efficiency is low in very hard rock [26, Sec 9, p 9].

Shot-drill holes from a few inches to 3 ft in diameter [26, Sec 9, p 61] may be drilled vertically to depths up to 1000 ft. For larger diameters or holes as much as 30° off vertical, depth, straightness, and progress are limited.

Percussion-drill holes from 1.5 to 3.0 in. in diameter may be drilled

in any direction, but are usually not over 100 ft deep. Holes up to 5 or 6 in. may be drilled vertically.

Diamond drills operate at any angle with hole diameters of 1.5 to 8 in. or more. Vertical or steep holes of moderate size may be drilled to thousands of feet [26, Sec 9, p 44].

Various devices have been used successfully for drilling large-diameter holes (3 to 8 ft) under special conditions, but to date applicability is limited. This is a field in which work is being done and in which progress should be made.

Most drilling is at a disadvantage in ground which is heavily fractured, cavernous, or which contains hard boulders, but many other conditions do not act equally in their effects on different types of drilling.

The conditions at any project should be studied by experienced drillers to determine what type of drilling would be most suitable, and what each might accomplish.

3-26 PROTECTION OF SECONDARY ENTRANCES. Secondary entrances, like primary entrances, may be protected by duplication, dispersal, blast doors, offsets, concealment, and provision for decontamination. Because of their size and cost, duplication, dispersal, and concealment are likely to be easier than for primary entrances. It should be noted that these entrances may be as vital as primary entrances.

SPACE LAYOUTS

3-27 REQUIREMENTS. Many installations will require connected and separated chambers, any of which may serve a purpose different from the others. Requirements may be any or all of the following:

(1) Dimensions, volume, shape, grades of roof and floor, and relative elevations of chambers will be determined by the use to be served by each chamber.

(2) The number of separate chambers, interrelations, and interconnections will be determined by the use each chamber serves, the protection requirements of each chamber, and any interference which might result from the activities to be carried out in any of the several chambers. Interference may be noise or vibration, or production of heat or fumes, all of which

are more difficult to handle in confined underground spaces than on the surface.

(3) Each portion of any installation should be studied to determine additional requirements, especially if these may be different from requirements for surface construction.

3-28 EFFECT OF CHAMBER SIZE, DESIGN, AND ARRANGEMENT ON UNIT COSTS. Paragraphs 3-38 to 3-41 list factors which affect unit excavation costs, and table 3.1 shows quantitatively how size is related to average contract costs.

3-29 ARRANGEMENT OF CHAMBERS. Arrangement is capable of almost any variation needed to meet requirements and conditions. Some typical arrangements are:

(1) Parallel chambers connected at one or both ends with long dimensions in any plane; they may be connected by smaller entrances at the top, bottom, or both, as may be desirable for reducing the cost of cutting the chambers, ease of ventilating them, or facilitating access

(2) Parallel chambers opened on each side of a connecting tunnel

(3) Parallel chambers connected at regular intervals throughout their length, resulting in a pattern of rectangular or rounded pillars

(4) Radial chambers connected at center, ends, and at regular intervals to form a spider-web pattern

(5) Chambers in concentric circles or tangents with radial connections (pentagon).

3-30 LOCATION OF SPECIAL CHAMBERS. Those chambers in which noise, vibration, heat, dust, or fumes are produced should be widely separated from other chambers in which these features would be detrimental. It will be easier to remove heat, dust, or fumes from special chambers if they are located above main chambers (nearer the surface). Ducts removing air from such chambers must lead to the surface rather than take foul air into other chambers. In planning the interrelation of chambers, the degree and type of protection required by each should also be considered. For example, the chambers containing products in storage may not require personnel in emergencies; plants for power, ventilation, and refrigeration might be separate because of production of noise, vibration, and heat, and they may function with minimum personnel.

3-31 DISADVANTAGES OF UNDERGROUND EXCAVATIONS. Some disadvantages of underground excavations are:

(1) Generally, greater cost and time are required for construction and for alterations.

(2) Cost and difficulty in dissipating heat and exhaust from power-generating equipment, or processes which generate heat, dust, or fumes may be a disadvantage.

(3) Psychological resistance to underground work may be met, though Panero [25d, p 1] has shown that this is easily overestimated. He suggests strict safety, neatness, and other means which may be used to make surroundings attractive.

(4) Entrance size and/or facilities such as shafts may limit the maximum size and weight of objects which can be moved into or out of underground excavations more rigidly than in the case of surface installations.

(5) It is more difficult to make available and to dispose of large volumes of process water.

(6) Excavations may require air conditioning and special rooms for prewarming incoming material to prevent condensation of moisture and consequent corrosion.

3-32 ADVANTAGES OF UNDERGROUND EXCAVATIONS. Some advantages of underground excavations are:

(1) Greatest conceivable protection is provided.

(2) Temperature and humidity are uniform, except as altered artificially.

(3) Absence of light may be an advantage in storing perishable substances.

(4) Moderately good insulating qualities of rock are an advantage in heating or refrigerating (refer to EM 1110-345-450).

(5) Weight and confining strength of rock may be utilized to make high-pressure storage of large volumes of fluids cheaper than surface storage.

(6) Rock walls require minimum maintenance, if any.

(7) Minimum surface area is required.

(8) Chambers are separated by pillars which form most effective fire walls.

(9) If layout makes it desirable to have one chamber above another, either separate or interconnected, such openings can be driven and serviced by means and equipment familiar to most underground miners.

3-33 CRITERIA FOR PLANNING FLUID STORAGE. The greatest latitude of design

is met in planning storage for fluids. Here the only requirements may be that chamber walls be tight and stable, withstand hydrostatic or other pressure, and do not interact with the product, that minimum cover be provided, and that product or products can be stored and retrieved at required rates. Access may be by any type of entrance which can be blocked to retain products and in which pipe and gaging equipment can be placed. Within limits such as these, the designer may plan openings of any size, shape, or arrangement calculated to produce lowest costs.

Absence of light and uniform cool temperature may be of advantage in storing some unstable substances. No safer storage place can be imagined for inflammable substances. If the substance to be stored is to be kept liquid or be reduced in volume by pressure, the confining strength and weight of rock may be utilized. For more detail on this subject see reference [21] which compares the costs of various types of surface and underground storage. The type most amenable to storage in underground excavations is pressure storage of liquid propane. Seven such storages are now in use in Illinois, Texas, and Oklahoma. In favorable rock and within the range of 30,000 to 270,000 barrels capacity, their cost has been between one-quarter and one-half the cost of equivalent surface storage in pressure vessels.

Time spent on underground propane storage projects has been:

Site study and planning	2 to 4 months
Construction (complete)	8 to 15 months

3-34 <u>SUGGESTED CRITERIA FOR PLANNING AN UNDERGROUND WAREHOUSE.</u> Storage for certain items may require air conditioning (see EM 1110-345-450). Refrigeration could be provided and little, if any, insulation would be needed since most rocks are fair insulators.

Walls and roofs should be stable and floors level. All should be clean.

Transportation requirements should be planned more carefully than for a surface warehouse because substantial alterations would be slow and expensive. Construction cost may be reduced if material can be stacked in high piles, but operating cost would be increased if proper handling were not provided.

Absence of light and uniform temperature may be advantageous in storing some materials.

Continuous pillars between chambers make excellent fire walls. Tight fire doors may be provided.

In other respects, the best practice in design of surface warehouses should be followed.

For more detail see reference [25c] in which Panero estimates comparative construction costs (1948 levels) based on a storage capacity equal to that of the Atlanta Depot. This involved capacity to handle 156,000 tons of supplies in and out per month. The site on which the estimate was based was on the Tennessee River near Chattanooga. Total excavation was estimated at 5,000,000 cu yd. Comparative constructions costs were estimated as:

Above ground	100%
In an existing mine	78%
In a new underground excavation	112.5 to 151%

and comparative operating costs as:

Above ground	100%
In existing mine	98.3%
In new underground excavation	98.8%

Time required for construction of the new underground depot is estimated at:

Site study and planning	4 to 6 months
Construction	20 to 24 months

Experience would indicate that it would be difficult under any circumstances to meet the time estimates and that an increase of 50 to 100 percent im time allowance might allow a fair increase in effectiveness of testing and design and in the efficiency of construction.

3-35 <u>SUGGESTED CRITERIA FOR LIGHT MANUFACTURING.</u> For some types of manufacturing the main problem may be dissipation of heat, fumes, and dust, especially during emergency operations. If a process can be shut down with a little notice and started without great loss of efficiency, the problem would be simplified.

If production of heat, fumes, or dust cannot be stopped readily in an emergency, there should be duplicate disposal facilities. These might take

heat or fumes to the surface, temporarily absorb them underground, or both.

In this type of installation, it will be especially desirable that heat-producing units be isolated, preferably above other space, and that ventilating and cooling facilities be at least partly independent.

With the exception of great room width, it should be possible to duplicate desirable surface-plant layout.

Unless moisture requires sealing or weak ground requires support, occasional rock bolts and cement paint should be adequate finish for walls and roofs. It is generally advisable to concrete floors for uniformity, to carry pipe and conduit, and to provide a base for equipment.

Transmission of vibration should be reduced by:

(1) Selecting equipment with minimal vibration

(2) Special mountings designed to absorb vibration

(3) Isolating vibration-producing equipment.

For more detail, see reference [25a] in which Panero estimates comparative construction costs (1948 levels) of a precision manufacturing plant similar to the Fire Control Instrument Division of the Frankford Arsenal. Concrete walls and roofs were planned in the main entrance, but elsewhere shotcrete (Gunite) was estimated except for occasional walls and floors. The estimate was based on a site near Dupo, Illinois, south of East St. Louis, where about 750,000 cu yd of excavation was planned. Comparative construction costs were estimated as:

Above ground	100%
In existing mine	119%
In a new excavation	144%

and comparative operating costs as:

Above ground	100%
In existing mine	101.7%
In a new excavation	102.6%

Time required for a new plant in a newly excavated site is estimated as:

Investigating and planning	6 to 8 months
Construction	12 to 15 months
Installation of equipment	3 months

3-36 CRITERIA FOR CONSTRUCTING UNDERGROUND FACILITY FOR OFFICE WORK. The following criteria were formulated for a hypothetical installation.

(1) A minimum cover was chosen.

(2) The number of entrances was determined, it being further decided that main entrance tunnels should extend through the hill with portals at both ends (refer to figure 3.3, p 11).

(3) A minimal warning period was assumed as a basis for the closing time required for blast doors.

(4) The positive and negative pressures to which the blast doors were to be designed were chosen.

(5) On the basis of judgment only, it was decided that rooms were to be 50 ft wide with 100-ft pillars between them, that the rooms and entrances should be arched, and that because of urgency, work would be done with available tunneling equipment and methods appropriate rather than by use of long holes. The contractors with whom this work was discussed had had little or no experience, equipment, or personnel to implement the latter method, which was carefully considered because it would leave roofs in less fractured condition.

(6) For greatest stability, to eliminate the necessity for utilities to cross the access tunnel, and to eliminate double sidewalks along the entrance, it was decided to open chambers from only one side of the entrance.

(7) To avoid need for elevators, it was decided that buildings to be built in the chambers should not be over three stories in height.

(8) The space required for equipment and for completely housing a given number of people was used as a basis for determining the building floor area. Additional area was then allowed for utilities for both emergency and regular use.

(9) Entrance size and type were decided on the basis of (a) usefulness and convenience in handling the anticipated personnel, and (b) the requirements of the desired construction schedule. For ultimate usefulness in emergency, it was decided that each entrance should accommodate two-way traffic.

(10) Entrances were to drain outward, though after the first few hundred feet one entrance was run downgrade to take advantage of the best portal site available.

(11) Roads in the area were studied and additions were made as inconspicuous as possible.

Actual work on a similar structure involved about 480,000 cu yd of total excavation; the total of all construction costs was about $33,000,000.

Time spent was:

Preliminary investigation of sites	4 months
Final investigation of preferred site	5 months
All construction	35 months

After completion of this project, it appeared that the rock was more fractured than was expected from examination of drill cores, and that the 50-ft room width was an effective maximum attainable in this rock only through the use of many rock bolts. If a duplicate installation were to be considered, it has been suggested that:

(1) More time be allowed, if possible, to check by core drilling the rock to be traversed by portals and entrances

(2) Long-hole mining and the use of a full concrete arch be considered as to their effect on time and cost as alternatives to the topheading tunneling method used, which required heavy expenditures and much time for scaling and rock bolting.

3-37 PROGRESS EXPECTATION. The following is intended for very general use in early approximations of work schedules. When a choice is narrowed to one or more sites, these figures should be checked by competent engineers or contractors who will evaluate the effects of local conditions. It is assumed that:

(1) Volume of work is at least moderate.

(2) Work is to be adequately planned, staffed, equipped, and supplied.

(3) Rock conditions, including the occurrence of water, are favorable or as noted.

(4) Work is on a three-shift-per-day basis.

As an aid to scheduling, the following data is given as an estimate of daily progress in the excavation and support of various entrances.

Type and Size of Work	Expected Progress Per 24-hr Day, lin ft
Full-face unsupported tunnels, from 8- by 8-ft cross section to 31 ft wide by 22 ft high	25
Full-face tunnels with steel supports installed, from 8- by 8-ft cross section to 31 ft wide by 22 ft high	10
Full-face unsupported inclines not steeper than 12% 8 by 8 ft to 31 ft wide by 22 ft high per heading	20
Full-face unsupported inclines not steeper than 30% 8 by 8 ft to 31 ft wide by 22 ft high, per heading	14
Shafts, vertical, including support	5

(Continued)

Type and Size of Work	Expected Progress Per 24-hr Day, lin ft
Raises, vertical, including support	8
Uncased diamond-drill hole, 3-in. diameter to 500-ft depth, noncoring, in hard compact rock, per drill	75
Uncased churn-drill hole, 4- to 9-in. diameter to 500-ft depth, in hard rock, per drill	45

Above-listed progress is considered fair for an average project, it being assumed that the type, size, and amount of equipment are suited to the cross section chosen. Some tunnel projects of intermediate cross section, organized primarily for speed, have more than doubled the progress shown above.

Tunnels of larger section will usually be more economically, but more slowly driven by widening a pioneer heading, which may be figured at above rates plus widening at rates up to 750 cu yd per day per face for widening substantial faces.

Progress in mass excavation with multiple, adjacent working places depends on capacity to break, load, and dispose of rock. Any operation may be bottlenecked by small entrances.

Examples:

(1) An excavation of 500,000-cu-yd volume with five to ten faces within an area of 1000 to 500 ft produced at an average rate of 2500 cu yd per day during approximately 8 months of peak production. This period was preceded by about 6 months during which entrances for truck haulage were driven.

(2) Another excavation of about 1,200,000-cu-yd volume, worked from 20 large chambers of uniform height, produced at a rate of 4000 cu yd per day for about a year of heavy production. This was preceded by about 18 months of entrance and access work by tunnels and shafts sunk on the center lines of each chamber. A belt conveyor was used to remove rock.

Various mining operations produce from 1000 to 10,000 cu yd per day through tunnels or shafts. These are operations of relatively long life, heavily equipped, and producing from many working places.

EXCAVATION COSTS

3-38 FACTORS GOVERNING EXCAVATION COSTS. These factors are divided into

three groups: general factors, design factors, and physical characteristics of rocks. These factors are considered to be the most important in governing cost of excavation. No attempt has been made to list them in order of importance because a factor of great importance in one project may be of small consequence in another.

3-39 GENERAL FACTORS.

(1) Excavation costs depend upon accessibility.

(a) Distance from highways, railroads, and other means of transportation.

(b) Distance from source of supply of services and materials, such as power, fuel, timber, structural steel, concrete material, explosives, etc.

(2) Excavation costs depend upon the topography as follows:

(a) In connection with its adaptability for work area, surface plant, and spoil. (Note: In some locations excavated material may be advantageously disposed of for fill, aggregate, or flux stone.)

(b) In connection with required cover as it affects entrances, in considering number of entrances desired, and whether they may be by tunnel or shaft, or by a combination of both.

(3) Availability of labor and housing.

(4) Availability of contractors, subcontractors, and appropriate equipment.

(5) Cost to acquire land.

(6) Climatic conditions affect surface construction, material handling, and ventilation.

3-40 FACTORS THAT REDUCE EXCAVATION COSTS. Conditions tending to reduce unit costs are:

(1) Volume of excavation. Large volume reduces write-offs of equipment, plant, and mobilization.

(2) Size uniformity. Uniformity of size permits selection of equipment to do work most effectively and permits an approach to standardization.

(3) Size of openings. Large openings permit most effective use of equipment, explosives, and labor, until size of openings requires extensive support of roof or walls.

(4) Multiple headings. Working on three or more connected headings will permit rotation of equipment and crews.

(5) Compactness of workings. Having working faces close together

reduces time in transporting crews, equipment, material, and spoil.

(6) Restriction of work to horizontal plane. All excavation done on a nearly horizontal plane permits complete use of mobile equipment.

(7) Simple, compact cross section. Simplicity of opening shape increases effectiveness of equipment, labor, and explosives, but cross section should be in keeping with rock structure.

(8) Simplicity of finish. Where rock permits, the least expensive procedure would be to scale chamber walls and back thoroughly. In some cases it may be desirable to paint walls and back with cement paint, or other readily placed coating, as a sealer and to improve appearance and safety.

3-41 ROCK CHARACTERISTICS GOVERNING EXCAVATION COSTS. a. Strength of Rock. This is strength as measured in testing machines, such as compressive strength and other similar characteristics. In the absence of physical defects mentioned below, strength determines the safe size of rooms and pillars.

b. Relative Freedom from Defects. Common defects in rock are jointing, fracturing, faulting, schistosity, cleavage, folding, crushing, and chemical alteration, such as the formation of weak clay minerals. Rock defects usually require the addition of artificial support.

c. Ground Water. Presence of ground water is especially costly if it is necessary to seal water from workings, or if workings must be entered through shafts. In horizontal or upgrade tunnels, the effect of small or even moderate amounts of water may be minor. If shafts are used as prime entries, any flow of water must be sealed completely or pumped as long as the shaft is to be kept open.

Hot water and explosive or poisonous gases are of rare occurrence, but when they do occur in excavations costs may be increased up to several times.

d. Other Physical Factors. The following factors have a minor effect on costs but any of them may be helpful in a given project:

(1) Easy drilling and breaking

(2) Stability on exposure to air or moisture

(3) Freedom from stickiness

(4) Low silica content, and a small amount of moisture which reduces dust problem

(5) Freedom from residual stress.

FUNDAMENTALS OF ROCK EXCAVATION

3-42 GENERAL DISCUSSION. Two general steps are conducted in excavation of rock: (1) drilling and blasting, and (2) loading and disposal of spoil. Simultaneously with these operations, provisions are made, where necessary, for mechanical ventilation, safety, and support. Coordination between all steps must be achieved in order to obtain an efficient and safe working cycle.

3-43 DRILLING AND BLASTING. The character of the rock determines the most advantageous pattern of drilling and blasting. Modern excavation practice has been to determine a pattern round by experimentation (see figure 3.4) and the crews are instructed thoroughly on this pattern until they are experts on obtaining the optimum breakage [40, Ch. VI]. The efforts to obtain these results are reduced by drill carriages or jumbos (illustrated in figure 3.5).

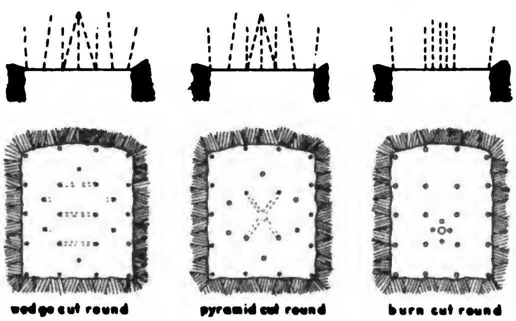


Figure 3.4. Arrangement of basic pattern rounds

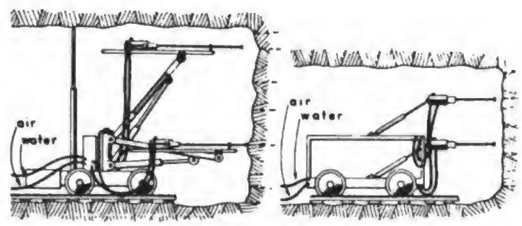


Figure 3.5. Jumbo

3-44 MUCKING. Efficient loading, or mucking, mainly involves securing mucking machines and accessory equipment of appropriate construction and design, and employing experienced crews.

In small headings (6 by 8 ft) the conventional up-and-over type of mucking machine operating on track is used extensively. Where cars can be supplied to the mucker continuously, a round opening 6 ft deep can be mucked in two hours.

Larger mucking machines of the up-and-over type are built on crawlers, as shown in figure 3.6. These machines are mobile and muck about 70 to 80 cu yd per hour. They compare favorably in capacity to the 1-1/4- to 1-1/2-cu-yd standard shovels mounted on crawlers.

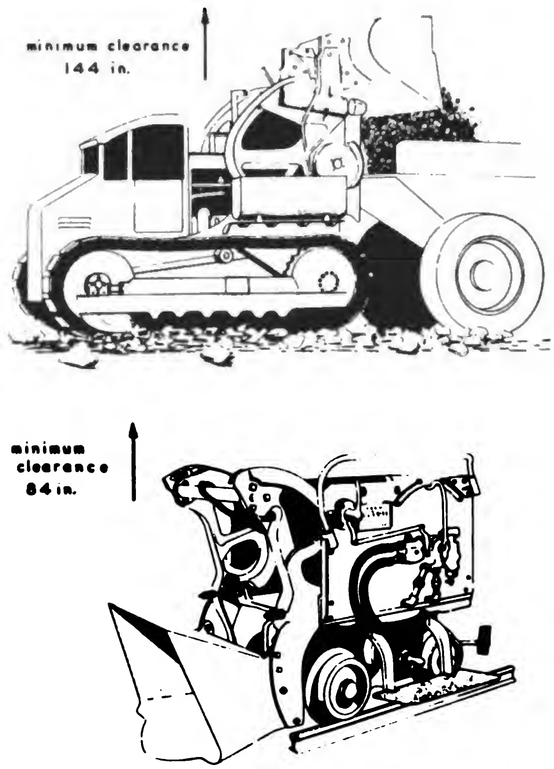


Figure 3.6. Common sizes, up-and-over loaders

3-45 DISPOSAL OF SPOIL. a. Track and Mine Cars. A common method of handling material in the mining industry is by track and mine cars, as shown in figure 3.7. Total loads up to 20,000 tons per day are moved over single track from multiple draw points and slushers. Side-dump cars have largely replaced end-dump cars because each car can be dumped without uncoupling. Speed of muck removal from tunnels is increased by use of auxiliary equipment to transfer cars behind the mucking machine as illustrated by figure 3.8.

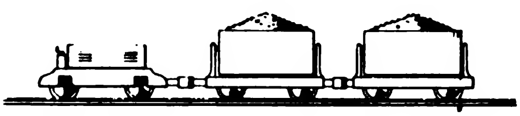


Figure 3.7. Locomotive track and cars

b. Trucks. To admit most trucks to the underground area for hauling units during excavation and for transportation of supplies and equipment requires a roof height of 13 ft and adequate ventilation. Trucks are more mobile than cars on track. They are very adaptable for removing muck from large mucking machines and shovels when mucking from faces in excess of

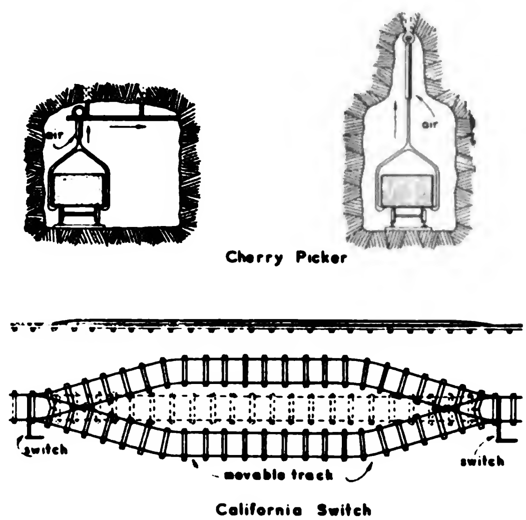


Figure 3.8. Car transfers

17 ft in width. Trucks operating underground must be diesel powered and supplied with suitable exhaust scrubbers.

c. Bulk Conveyors. Disposal of spoil by conveyors involves the use of a main conveyor or conveyors, with a system of feeders. Material is transported directly to the dump. This system in some respects is more economical than the train of cars or trucks. However, conveyors definitely lack the flexibility required in mass excavation projects.

3-46 VENTILATION. Explosions, fumes, hazardous dust concentrations, and loss of efficiency can result from inadequate ventilation. As most excavations are dead-ended while being driven, ventilation is particularly important in mass excavation projects. Each man requires from 150 to 500 cfm, and each diesel engine properly adapted for underground work requires 75 cfm per rated horsepower.

Natural ventilation is helpful, but mechanically induced ventilation is essential on every excavation job of any size. Three systems of induced ventilation are used in most modern underground excavations.

(1) The most common system is to place the fan or blower close to a portal and force fresh air into the working place through thin-wall metal pipes; the exhaust air then leaves through the portal. The greatest disadvantage of this system is that noxious fumes, if present, contaminate all the underground workings.

(2) The reverse of system (1) is used where the fan or blower at the entrance exhausts through the duct and the tunnel length is the intake. This method has two disadvantages: first, in cold climates, frost may form on the bottom and sides of the portal if there is any seepage; second, fresh air does not circulate beyond the end of the duct.

(3) The recommended method is a reversible fan placed close to the portal. Immediately after the blast the fan exhausts air from the headings, removing the obnoxious fumes immediately. Later the fan blows air into the tunnel and the foul air leaves through the portal. This method has two advantages: first, the fumes from the blast do not contaminate the air in the rest of the workings; second, fresh air goes directly to the face where most of the men are working. In multiple headings auxiliary fans may be placed to blow the incoming air up to the faces.

3-47 SAFETY. Rapid excavation of underground space requires a high degree of activity concentrated in a relatively small area. This condition demands work to be done in a safe manner if the project is to be completed

on schedule. Work should be performed in accordance with local, State, and Federal laws as applicable, and Bulletin No. 439 of the U. S. Department of the Interior, Bureau of Mines.

During underground excavation the principal conditions that must be observed are:

(1) Careful scaling of all working faces before work is resumed after blasting

(2) Correct blasting practices:

 (a) Heading properly guarded during blasting period

 (b) Proper handling of explosives and detonators

 (c) Precaution while connecting rounds, proper electrical connections, and care that no outside source of stray current can be introduced

 (d) Checking face after blast, and properly handling misfired holes

(3) Dispatching and traffic control of trucks and equipment

(4) Adequate ventilation and light at all working faces

(5) Proper safety clothing, protective shoes, hats, and gloves

(6) Removal of all debris, equipment, and materials not necessary for progress of work

(7) Use of diesel equipment restricted to places where positive ventilation is maintained by mechanical ventilation

(8) Haulage roadbeds kept well surfaced and drained, with enough clearance between walls and piles of material so that workmen cannot be trapped

(9) Use of only fume Class I explosives as defined by the Bureau of Mines

(10) Haulage equipment well marked with reflectors, and headlights and taillights

(11) Bells or other sound warnings sounded before equipment is moved

(12) Only operators allowed to move mechanical equipment, even if only for a few feet.

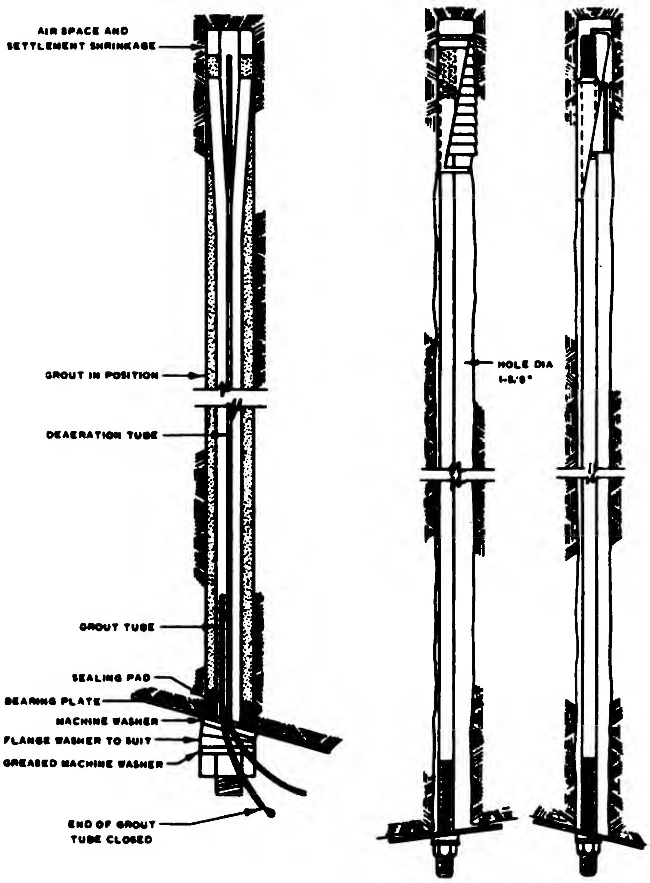
3-48 SUPPORT OF OPENINGS. The limitation of time available to complete mass excavation for military purposes may preclude any attempt to excavate in ground that would require more than occasional support in the chamber area. If wide spans require support, it would be advisable to change the chamber design to narrower and longer chambers. Local areas of bad ground

may be encountered, especially in the main entries to the chamber areas. The usual methods of support are described in the following paragraphs.

3-49 PILLARS. The pillar is the most important element of support. Design plans should be flexible enough to change the pillar area, if necessary, after the excavation indicates weakness that is not manifest at the beginning of the program.

Pillar areas may vary from 40 to 60 percent of the total area. Main entry pillars are usually from 25 to 50 ft wide (see EM 1110-345-432, [40, p 367], and [26, p 10-134]).

3-50 ROCK BOLTING. Systematic rock bolting, in lieu of other means of support, has recently come into widespread use in mining and tunnel construction. Rock bolts have been used as means of roof reinforcement in underground military installations in rock built within the past ten years. Rock bolts are steel bars inserted in drill holes in the roof and occasionally in the sides of tunnels. The inserted end has a device which permits it to be firmly anchored in the hole. The projecting end is fitted with a plate, nuts, and washers, as shown in figure 3.9, whereby a prescribed tension can be developed in the bolt by means of an impact wrench, thus prestressing the surrounding rock.



GROUTED SLOT AND WEDGE BOLT SLIDING WEDGE BOLTS

Figure 3.9. Rock bolts

For maximum accomplishment, either as a safety precaution or to develop maximum resistance to shock from effects of nuclear weapon explosions, a regular pattern should be employed. In tunnel sections the bolts should extend radially around the roof from

the springing lines as shown in figure 3.9. The minimum length of a rock bolt should be 6 ft and the maximum practicable length is about 20 ft. It is convenient to consider a pattern of rock bolts in terms of the length-spacing ratio. From photoelastic studies it has been determined that the minimum value of the length-spacing ratio should be of the order of 1-1/2 to 2+ to be certain of developing a zone of uniform compression [2]. Model studies also show that an approximate picture of the depth of the zone of uniform compression developed by bolt pattern in homogeneous rock may be gained by assuming a spread of pressure of 45^{o} from the head and anchor end of each bolt [2]. Where rock bolts are installed at random in areas assumed to be weak, the direction and length of the rock bolts used are chosen so as to intersect the zone of weakness at right angles. They are made to extend through the questionable rock into a sounder formation for a sufficient distance to develop anchorage.

a. Roof Support Accomplished by Rock Bolting. Rock bolts furnish support by the creation of a zone of radial compression on the rock acting along the direction of the rock bolts while at the same time causing tangential compressive stress in the rock at the anchor end of the rock bolts. This acts at right angles to the direction of the rock bolts and is produced by the interaction of the tension created in the bolt and the wedging action of the anchorage. It has the effect of reducing the peak

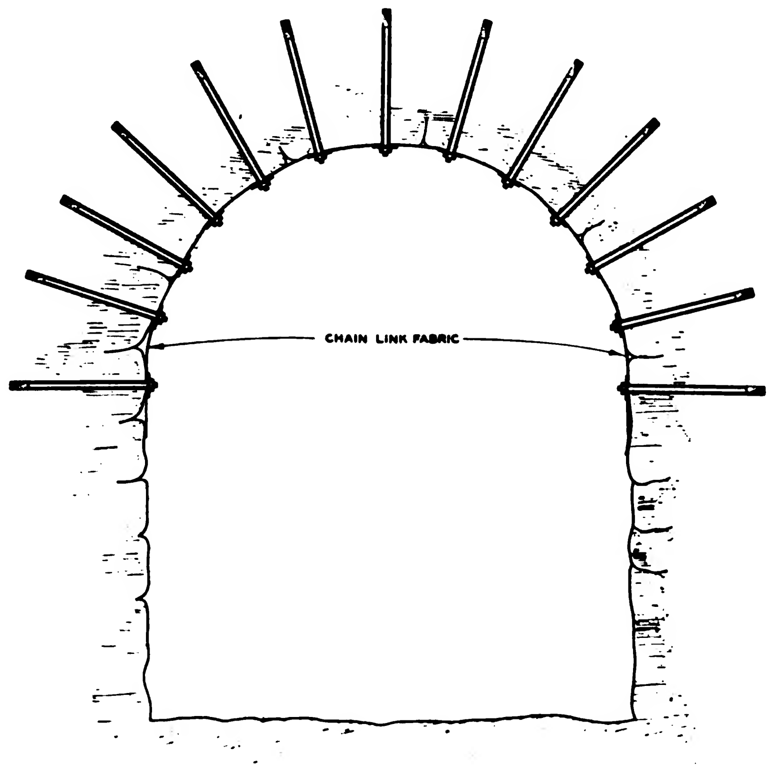


Figure 3.10. Rock bolt pattern

tangential stress at the surface of the opening. These two effects combine to reduce the difference between the vertical and horizontal stresses in the vicinity of the opening. The stress conditions tending to cause failure of the rock are thereby reduced in magnitude [2].

Loosened rock in the vicinity of the bearing plate of the rock is prevented from moving into the cavity. The mutual interaction of a pattern of rock bolts, such as shown in figure 3.10, prevents the dilation of the surface material into the cavity under the influence of the stresses around the opening. Thus, the active pressure of the loosened rock is restrained by using the rock bolts to mobilize the passive resistance of rock situated at a distance from the opening [2].

b. Justification of Rock Bolting. In protective structures rock bolts are used to create maximum strength conditions and thereby increase the factor of safety against spalling and roof falls resulting from shock induced by weapons of attack. Where requirements are less rigorous, rock bolts may be used only in isolated areas where the rock is nonhomogeneous and weak rock is exposed during excavation. Rock bolts are primarily used to create a structure of uniform strength. The decision to augment rock bolting by attachment of beams, channels, and wire mesh is largely a matter of judgment with respect to local conditions. "Guniting" and grouting will not add appreciably to the strength of an installation but may be required to ensure the life of a structure. The requirement for Gunite is generally a function of moisture and acid content in the rock formation.

c. Advantages of Rock Bolts. Rock bolts can be installed in a working face immediately after blasting and scaling or barring. Thus, safe conditions can be created in a minimum of time. The use of rock bolts permits a smaller tunnel excavation to obtain finished dimensions, thus making a stronger opening with less excavation. Little, if any, special equipment is required although a drilling carriage or jumbo may be used advantageously where a regular pattern is used.

d. Wire Mesh with Rock Bolts. Wire-mesh lagging can be used to secure small blocks of rock that have been loosened between neighboring rock bolts. The mesh is flexible and should be drawn tightly against the surface irregularities. The mesh can be installed by use of short bolts

immediately after blasting and scaling operations have been completed. The regular pattern of rock bolts can then be installed by drilling through the mesh. Where conditions are good the mesh can be installed in the same operation with the rock bolts just prior to tensioning the bolts. Gunite may be applied to cover bearing plates and wire mesh to eliminate corrosion. It may also be advantageous to grout around the rock bolts as shown in figure 3.9. Grouting should be done after the bolts have been tensioned.

3-51 SHOTCRETE. Shotcrete or Gunite is a mixture of cement, sand, and water placed on a cleaned rock surface by a compressed-air gun. The mixture cannot be placed on rock surfaces subject to water seepage. It may be placed with or without wire-mesh reinforcement. Without reinforcing the usual thickness is 1/4 to 1/2 in., but this is usually exceeded if reinforcing is used. It has little mechanical strength if applied in a thin coat without reinforcing, and the mechanical strength of thicker coats, while appreciable, is indeterminate. While shotcrete is not by any means impervious, it has virtue in retarding transfer of moisture into or from a rock surface, and may be considered a partial seal. It is usually placed in layers about 1/4 in. thick and each layer is allowed to set, at least partially, before the next layer is placed [26, p 7-20].

3-52 TIMBER AND STEEL SETS OR ARCHES. Timber and steel sets are commonly used where rock requires more support than can be provided by means already listed. A three-piece timber set (two posts and a cap) with bracing between sets, and partially or completely lagged with plank, is commonly used for temporary support of small openings. Where larger sections require support, a five- or seven-piece timber arch is used. If greater strength is needed, sets made from joined or curved steel beams are preferred. In every application of timber or steel it is vital that blocking be carefully placed and wedged above the set to support rock overhead. In blocking jointed sets, whether of timber or steel, it is important that the blocks

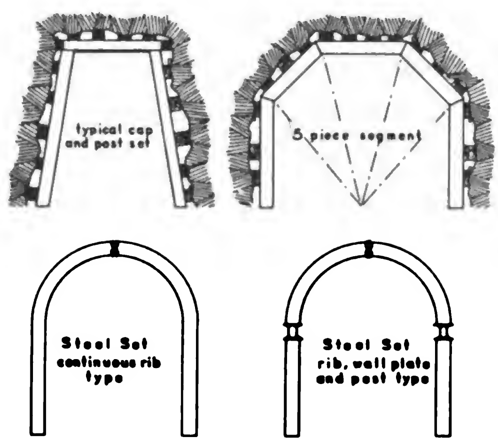


Figure 3.11. Timber and steel sets

apply pressure to the set on, or close to, the joints (refer to figure 3.11 and [30, p 354-372], or [26, p 6-21 to 6-23]).

3-53 <u>PLAIN AND REINFORCED-CONCRETE LINING.</u> Plain and reinforced-concrete lining may be used as discussed in EM 1110-345-432. It may be placed directly against rock which is otherwise unsupported or it may cover rock bolts, shotcrete, or steel or timber sets, which have been placed for temporary support [30, Ch. 22, p 373].

3-54 <u>GROUT.</u> Grout is any substance introduced to block channels in rock. The most usual substance is cement and water. To plug large cracks, sand, sawdust, or other admixtures are commonly used. Grout may be introduced through relatively short holes drilled from a tunnel or shaft or through longer holes drilled from the surface in advance of excavation. Grout must be pumped at a pressure which definitely exceeds hydrostatic water pressure in the fracture to be sealed. Confinement of grout is secured by the use of rubber packers, which are expanded against the walls of a drill hole, and through which grout is pumped. Where it is necessary to seal fine cracks, plastic agents are preferred because they initially are liquids (refer to figure 3.12).

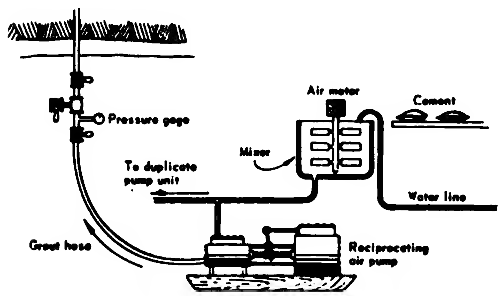


Figure 3.12. Grout machine

The principal drawbacks of grouting are the uncertainty of the direction the grout will travel after it leaves the hole through which it is placed, and the possibility that clay and other incompetent material may obstruct or partially block channels which it is desired to seal.

To test the effectiveness of grout the area grouted should be test drilled [30, p 410-413]. Grout holes deeper than 20 to 25 ft are drilled by diamond drills or long-hole percussion drills by equipment of the nature illustrated in figure 3.13.

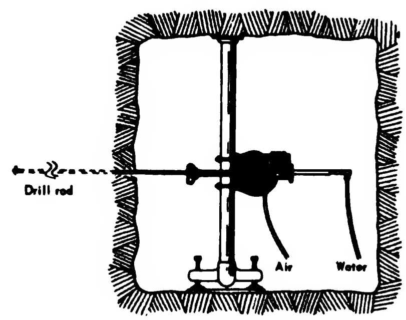


Figure 3.13. Diamond drill

Costs vary greatly depending upon the amount of grout pumped at one time, the number of holes required, and the manner in which they are

drilled. Cost of mobilization and demobilization of equipment is high.

3-55 SPECIAL METHODS OF SUPPORT. Special means of support and stabilization during construction, which occasionally have important application, are as follows:

(1) Liner plates with or without ribs

(2) Dewatering (through wellpoints, deep wells, or by air pressure)

(3) Application of asphaltic coatings to surfaces which deteriorate on exposure to air

(4) Freezing to consolidate saturated sands, silts, and clay.

3-56 EXCAVATING EQUIPMENT. The factors that influence the selection of equipment depend on the nature of the project and the methods of solution devised by the individual contractor or contractors. The contractor's personal experience and the recommendations of his trusted supervisors, rather than formulae, finally control the selection. The size of the equipment is governed by the entrance cross section and the amount of equipment depends upon the size of the project, time for completion, and number of headings.

The fundamentals of rock breaking, removal, and support are similar in all types of underground work: tunneling, sinking inclined or vertical shafts, raising or excavating large openings. The detailed application of these fundamentals varies considerably.

HORIZONTAL TUNNEL IN INTACT ROCK

3-57 GENERAL. Equipment and excavation methods for various-size workings (figure 3.14) may vary with the experience of contractors and their working

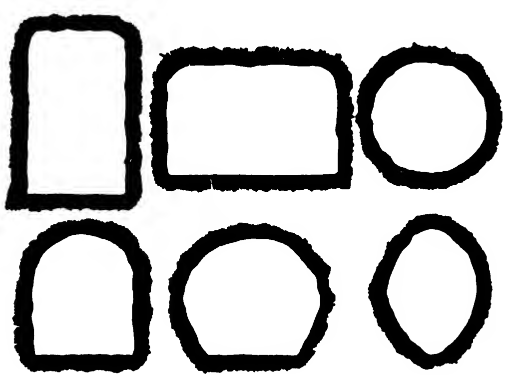


Figure 3.14. Types of openings

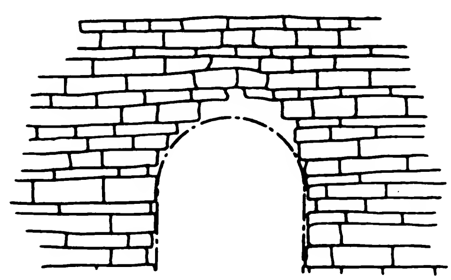


Figure 3.15. Overbreak in horizontally stratified rock

personnel. The following, however, represents what is considered normal practice for different size workings. Three sizes of tunnels are considered as of greatest applicability. They are as follows:

(1) Tunnels up to 12 by 12 ft in section. These may be used as secondary entrances (for ventilation, power cables, etc.) and as pioneer headings to be enlarged later. Ordinarily they are driven with rail haulage because they are not large enough for trucks or truck-loading equipment.

(2) Single-lane highway or single-track railroad tunnels (17 ft wide by 18 to 22 ft high). These may be driven with trackless equipment. Pioneer headings not less than 17 ft wide by 13 ft high fall in this class. (Chicago, Milwaukee, St. Paul, and Pacific RR considers 17 by 22 ft and 31 by 22 ft standard, respectively, for single- and double-track tunnels.)

(3) Two-lane highway or double-track railroad tunnels (31 ft wide by 20 to 25 ft high or larger). These may be driven by trackless equipment.

3-58 TUNNELS UP TO 12 BY 12 FT. Headings are run full face [30, p 300]. Principal equipment for the several operations is as follows:

(1) Leyner drills mounted on a jumbo which travels on track, or airleg drills. A staging or deck is required to drill horizontal holes which are more than 8 ft above grade

(2) Up-and-over loader on rail

(3) Side-dump cars, height governed by loader specifications and width governed by passing arrangements. Locomotives are generally from 1 to 5 tons [33, p 284]. Battery or diesel locomotives are preferred. A car passer or cherry picker is illustrated in figure 3.8, and described in [30], pp 103-105. Track may be 24- to 36-in. gage and must be heavy enough to support loads and avoid derailments.

Branch tunnels, not over 300 ft long, may be mucked by two- or three-drum slushers which move rock to a main heading.

3-59 SINGLE-LANE HIGHWAY OR SINGLE-TRACK RAILROAD TUNNELS (17 ft wide by 18 to 22 ft high). Headings for this size tunnel may be driven by any of the four following methods.

a. Full Face. Headings are driven full face. Principal equipment for the several operations is as follows:

(1) Leyner drills mounted on a jumbo which travels on crawlers or pneumatic tires. Airleg drills operating from a platform jumbo could be used

(2) Up-and-over loaders of about 1-cu-yd capacity on crawlers, diesel or electric powered

(3) Diesel trucks of 6- to 10-cu-yd capacity. Unless trucks can travel without turning, turnouts are required.

b. Bottom Heading, Widened by Ring Drilling. A pioneer heading up to 9 by 9 ft is driven on grade and center line as described in paragraph 3-58, and is widened by blasting rings of holes drilled at right angles to the center line, each hole of correct length to break to the desired size [30, p 306].

Principal equipment for the pioneer heading is as described in paragraph 3-58, and for widening is as follows:

(1) Leyner drills mounted on a horizontal bar held by two upright columns

(2) Up-and-over loader on crawlers

(3) Diesel trucks.

c. Top Heading, Widened by Benching or Ring Drilling. A pioneer heading is driven full face as described in paragraph 3-58, its top coinciding with the top of the completed excavation. This heading may be about 8 by 8 ft or full width. Principal equipment for the pioneer heading is described in paragraph 3-58, but if this heading is to be full width, double track is necessary.

If the pioneer heading is full width, the bench is removed by blasting down holes. Principal equipment for widening is:

(1) Wagon drills or sinkers

(2) Up-and-over loader

(3) Diesel trucks.

If the pioneer heading is about 8 by 8 ft, ring drilling is recommended to widen to size desired. The principal equipment for widening is described in paragraph b above.

d. Bottom Heading, Widened by Long Holes. A pioneer heading is driven as in paragraph 3-59b; principal equipment is described in paragraph 3-58. This heading is widened to full size by blasting long holes drilled parallel to the center line. These holes are drilled from drill

stations or "slots." Principal equipment for widening is as follows:

(1) Diamond drills or Leyner drills mounted on bars with jointed steel

(2) Up-and-over loaders

(3) Diesel trucks.

3-60 TWO-LANE HIGHWAY OR DOUBLE-TRACK RAILROAD TUNNELS (31 ft wide by 20 to 25 ft high or larger). Headings for this size tunnel may be driven by any of the four following methods.

a. Full Face. Heading is driven full face. Principal equipment for the several operations is:

(1) Leyner drills mounted on a jumbo

(2) Short boom, diesel or electric powered, revolving shovels on crawlers, or up-and-over loaders

(3) Diesel trucks of 10- to 16-cu-yd capacity.

b. Bottom Heading, Widened by Ring Drilling. The method is as described in paragraph 3-59b. Principal equipment for driving the pioneer heading is as described in paragraph 3-58 (with track) or as described in paragraph 3-59a (trackless). Principal equipment for widening is:

(1) Leyner drills mounted

(2) Shovels

(3) Trucks.

c. Top Heading, Widened by Ring Drilling. A pioneer heading is driven with or without track. The top of the pioneer heading coincides with the top of the completed excavation. It is widened by ring drilling. Principal equipment is:

(1) Leyner drills on bars

(2) Shovels

(3) Trucks.

d. Bottom Heading, Widened by Long Holes. The method is described in paragraph 3-59d. Principal equipment for driving the pioneer heading is described in paragraphs 3-58 and -59a. Principal equipment for widening is:

(1) Diamond drills or Leyner drills mounted on bars

(2) Shovels

(3) Trucks.

(For further details on tunneling in rock see reference [30, Ch. 18, p 300].

3-61 HAULING AND DUMPING. Factors that affect the average travel time between excavation and dump are:

(1) The distance between disposal site and portal

(2) The grade and condition of haulage roadways. For rail haulage it is desirable to have grade close to 0.5 percent in favor of the load, and track must be well maintained. For truck haulage level roadways are preferred, but grades up to 10 percent can be negotiated with some reduction in speed and additional maintenance costs

(3) The method of car dumping. For rail haulage, side dumping is preferred since cars do not have to be uncoupled

(4) Physical characteristics of the dumping station. Dumps and approaches must be adequate and well maintained to avoid haulage delays.

3-62 SUPPORT IN TUNNELS. A great majority of tunnels in rock require support at some part of their construction or use, and each condition merits immediate attention. The cardinal rule of support underground is "support the rock mass before it has a chance to move." One exception to this rule is in the case of swelling ground.

On-the-spot judgment is necessary to meet local conditions, but if extensive timbering is necessary, a planned method should be studied so that placing of supports is coordinated with the drilling, blasting, and mucking cycle.

3-63 SPECIAL SUPPORT METHODS. a. Forepoling or Spiling. In this method, timber or steel beams are driven divergently ahead of last set to form a shield within which next set of timber is erected. This system is used in small headings driven in sand or clay [26, p 6-25]; [30, p 207]; [40, p 347]. See figure 3.16.

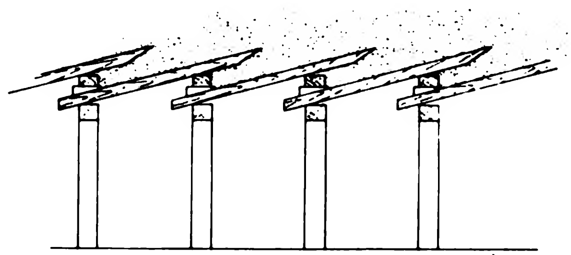


Figure 3.16. Method of forepoling

b. Booms. In connection with spiling or even without it, timber or heavy-duty pipe booms may be carried ahead of last set of timber to support

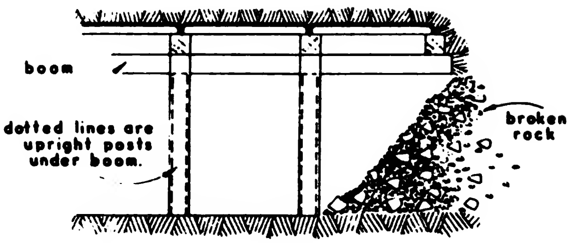


Figure 3.17. Method of booms

rock over the muck pile until the muck can be removed and posts placed [30, p 207]; [26]. Refer to figure 3.17.

c. Needle Beams. These are used in heavy ground in heading and bench attack. Roof is temporarily supported on trench jacks, then transferred from jacks to needle beam, bench is removed, and posts are set under arch segments as work progresses [30, p 228]. Refer to figure 3.18.

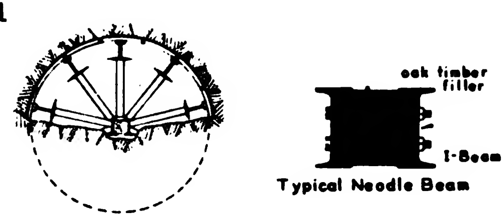


Figure 3.18. Needle beam method

d. Flying Arch Method. This method is similar to the use of a needle beam, except that the top arch is concreted before the bench is removed. Temporarily, this concrete is supported on posts until it can be supported permanently by concrete placed in the invert section of the tunnel [30, p 229]. Refer to figure 3.19.

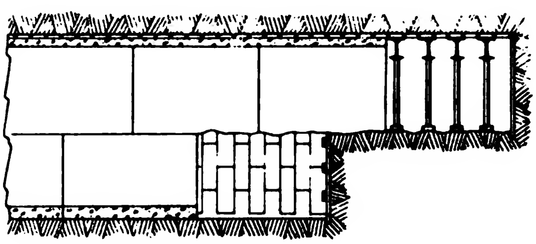


Figure 3.19. Flying arch method

e. Shields. Soft clay and silt are sometimes penetrated by the use of a shield, which is forced ahead of support by hydraulic jacks. Liner plates, which are flanged segments of sheet steel, are used in conjunction with a shield. They are erected inside the tail of the shield to form complete circular rings and are suitable for withstanding pressure until concrete is placed inside them [30, p 233].

f. Plenum Process (Compressed Air). Where silts and sands are poorly consolidated and saturated, the excavation is done under air pressure which is slightly higher than the hydrostatic water pressure and which, therefore, dehydrates and stabilizes the ground in the periphery of the heading. This minimizes running ground and allows miners to excavate and place support [30, p 275].

METHODS AND EQUIPMENT FOR EXCAVATING HIGH CHAMBERS

3-64 GENERAL. It is assumed that openings are to be driven in intact rock. Chambers in rock are classified as follows: (1) long chambers, and (2) high chambers. The dimensions of long chambers fall in the category of tunnels described under horizontal tunnels. High chambers may be excavated efficiently because of the small amount of horizontal development work required.

3-65 METHODS FOR CUTTING HIGH CHAMBERS. a. Benching. Preparatory to enlarging the chamber to the desired size, a small tunnel is driven at the bottom of the chamber and a raise of small cross section is driven to the roof of the chamber. A bench is cut from the top of the raise exposing the top of the chamber. The remainder of the chamber is excavated by drilling down holes, and the broken rock is removed from the bottom of the raise. The benches may be multiple, one above the other, so that most of the broken rock falls directly into the raise.

Equipment for the bench slabbing is either hand-held, air-operated sinkers, or wagon drills.

The haulage equipment, as described in paragraphs 3-57, 3-58, and 3-59, suffices for the benching stage. Stopers are used in the raise driving.

The size and height of the chamber are governed by the stability of the back and the thickness of the firm strata [40, p 144]. Refer to figure 3.20.

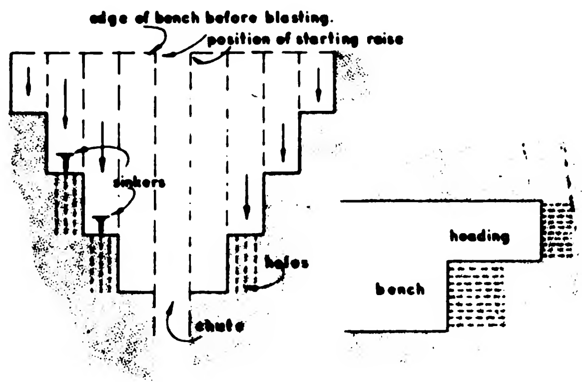


Figure 3.20. Benching

b. Shrinkage. Preparatory to enlarging the chamber by the shrinkage method, a tunnel must be driven in the bottom of chamber area. In this method, the miners work on top of broken rock to drill and blast. In order to do this, close control of muck removal is necessary, and about one-third of the broken rock is removed during the mining stage.

Drilling may be done by stopers drilling vertical holes, Leyners

drilling short horizontal holes, or diamond drills or percussion drills drilling long horizontal holes.

The size and height of the chamber are governed by the stability of the roof and by the thickness of the firm strata.

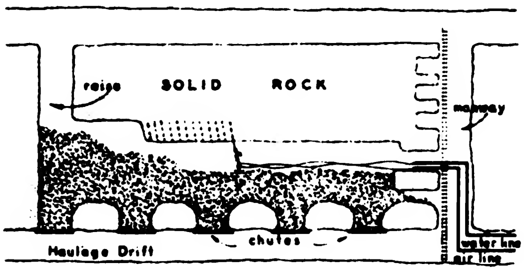


Figure 3.21. Shrinkage method

Haulage equipment used is the same as in benching.

Stopers are preferred for excavation to enlarge the chamber; however, diamond drills, long-hole percussion drills, and Leyners are also used successfully [28, p 576-579, 599]; [9], p 52-53]. Refer to figure 3.21.

c. Sublevel Stoping. Preparatory to enlarging by the sublevel stoping method, a tunnel must be driven in the bottom of the chamber area and small cross-section raises and subdrifts are driven outlining the boundary of the finished chamber. The miners drill from benches or from the sublevel drifts and not in the completed excavation.

The size and height of the chamber are governed by the stability of the back and by the thickness of the firm strata.

Sinkers, stopers, and long-hole percussion or diamond drills are used for drilling holes.

Haulage equipment used is same as benching [40, p 564-568, 597-598]; [9], p 53]. Refer to figure 3.22.

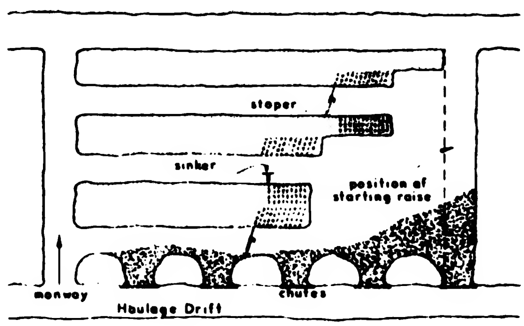


Figure 3.22. Sublevel method

METHODS AND EQUIPMENT FOR SINKING VERTICALLY

3-66 GENERAL. In defense projects, shafts may be used for entrances to chambers which are below the level of the surface. Work is planned from information obtained from site examination. Methods should be sufficiently flexible to accommodate weak or water-bearing zones, which may be

encountered. (For details see [26, Sec 7, p 7-01]; [30, Ch. V, p 72]; and [9, Ch. I, p 1].)

3-67 CROSS SECTION. The cross section must be adequate for all requirements during and after sinking, such as rock removal, service (power, communications, compressed air, ventilation pipe, water lines, pipe column, facilities for handling material, equipment, and personnel), and for manway. Two commonly used shaft sections are rectangular and circular [26, p 7-03]; [9, p 7]; [36].

3-68 RECTANGULAR SHAFT. In small rectangular shafts (width 5 to 7 ft, length 10 to 15 ft) the bottom is advanced by using the center wedge cut or the end wedge cut, as shown in figure 3.23A and B.

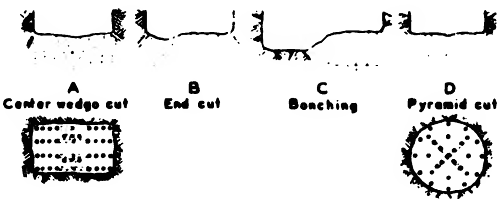


Figure 3.23. Drilling pattern for shaft sinking in rock

Large rectangular shafts are frequently "benched" to balance mucking and drilling crews, as shown in figure 3.23C. The drill equipment consists of:

(1) Sinkers

(2) Leyners mounted on cross bars, or specially designed drill carriages held in place above the shaft bottom by hydraulic or mechanical jacks. In small cross sections, mucking equipment consists of round-point shovels and two sinking buckets. One loaded bucket is hoisted to the surface while the second bucket is being filled. Large cross sections permit the use of a clamshell type of shaft mucker (figure 3.24) and buckets or skips.

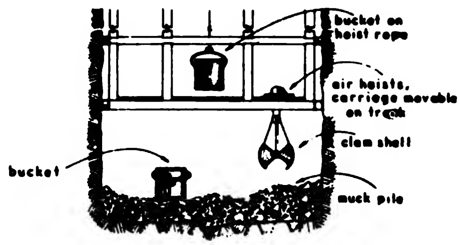


Figure 3.24. Shaft mucker

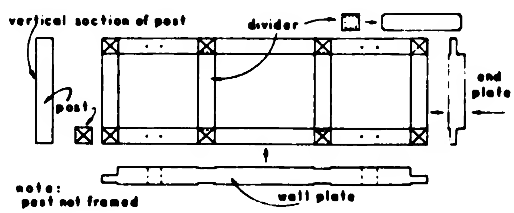


Figure 3.25. Shaft set

The support is timber or steel sets, and lining is timber or concrete [30, p 76 and 77]. Refer to figure 3.25.

3.69 CIRCULAR SHAFT. The circular cross section withstands ground pressure better than the rectangular section. However, it requires about 25 to

40 percent more excavation than rectangular shafts of the same capacity, for handling supplies. The drilling and blasting, mucking, and timber cycles follow the same pattern as for rectangular shafts. The recommended drill round for circular shafts is the pyramid cut (figure 3.23D). Shaft lining is usually concrete. The concrete forms are collapsible and are lowered into place [9], p 7-18].

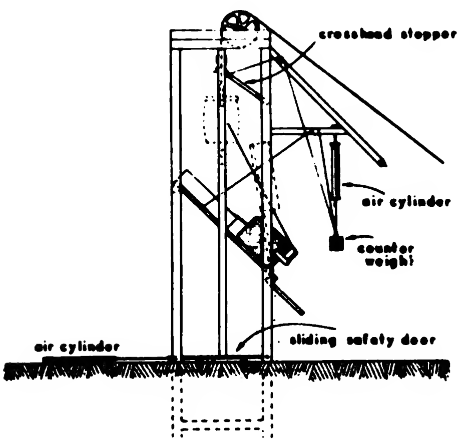


Figure 3.26. Shaft head frame and dumping arrangement

3-70 SURFACE EQUIPMENT. The surface equipment, compressor, dump-disposal arrangement, etc., are the same as for tunnel driving. Additional equipment necessary for shaft sinking consists of the hoist, head frame, and dumping arrangement (figure 3.26). (For details on mine hoists see [33, p 131]; for details on head frames see [33, p 71]; for details on skip-dumping arrangement see [9, p 12-113]; and for details on buckets and crossheads see [9, p 12-91 to 12-97].

3-71 SINKING IN SOFT GROUND. Shafts have been sunk successfully through soft, weak, water-saturated, and swelling ground by special methods. These methods are expensive and the progress is slow.

a. Plenum Process (Compressed Air). This process when used for shaft sinking is the same as described in paragraph 3-63. Muck is spaded and hoisted to the surface in buckets. Equipment necessary is spading tools, round-point shovels, two small shaft buckets, auxiliary air tuggers, air locks, compressors, and decompression chambers [30, p 275].

b. Drop Shaft. A hollow cylinder of reinforced concrete is constructed on the surface with its axis vertical and its wall tapered outward to a cutting edge. The cutting edge is forced downward by the weight of the caisson above it, penetrating the ground [9, p 8-06]; [30, p 87]. Successful drop shafts deeper than 200 ft are rare because of the difficulty of maintaining line; this difficulty is reduced by using pneumatic caissons [30, p 88]; [9, p 8-12].

c. Poetsch Method (Freezing). Its essential feature is to solidify

water-bearing ground by freezing it. Shafts have been sunk by this method to depths ranging from 100 to 2000 ft [9, p 8-20]. Conventional sinking equipment is used after the shaft pillar is solidified (paragraph 3-68).

d. Predraining. The shaft pillar is dewatered or partially dewatered by drilling holes several feet from the shaft, placing deep well pumps in the holes, and lowering the water level by pumping water to the surface.

Predraining a shaft pillar can be achieved by using wellpoints [30, p 282 and 283].

e. Cementation and Grouting Methods. In this method, the shaft pillar is prepared by drilling long diamond-drill holes, 2-1/2 to 3 in. in diameter, and grouting as described in paragraph 3-54. After drilling to test the pillar, shaft excavation is begun by using standard shaft-sinking methods and equipment as described in paragraphs 3-68 and 3-69.

This method is sometimes modified by drilling and grouting in stages. Shorter diamond-drill holes or percussion-drill holes are drilled, and the pillar is grouted 40 to 50 ft in advance of excavation [9, p 8-23].

METHODS AND EQUIPMENT FOR SHAFT RAISING

3-72 GENERAL. When an additional opening is needed for existing workings, a shaft may be raised instead of sunk. Raising is cheaper and faster than sinking.

a. Pioneer Raise and Sinking. Two stages of excavation are used. In stage 1, a small raise (about 5 by 8 ft) is excavated in the center of the shaft section. Muck is removed by mucking machine or pulled from chute at bottom of raise; miners drill back of raise from staging using air-operated stopers.

In the second stage, the shaft is enlarged and support placed by starting from the top and drilling down holes and breaking the rock to the small raise, after which support and lining are placed. The muck is removed from the bottom of the raise Support and lining materials are lowered from the surface.

Equipment used in the second stage is the same as described for sinking shafts in paragraph 3-68. Stopers are used for stage 1.

b. Full-Face Attack. The raise is excavated, using the full-face attack method. One shaft compartment is lagged off and used for muck transfer, and a second compartment is used to hoist men, equipment, and supplies. Drill equipment used is stopers or jack legs. Progress is slow using this system and good ventilation is hard to maintain.

c. Pioneer Raise and Raising. The first stage is the same as stage 1 in paragraph a on preceding page. In the second stage, shaft enlargement is begun from the bottom. One compartment is used for muck transfer and the second compartment is used to hoist men, equipment, and materials. Men, materials, and equipment can be lowered from the surface also if more convenient. Equipment used is the same as described in paragraph b above.

d. Diamond-Drill Hole, Pilot Raise, and Shrinkage. This method is adaptable only for shaft raises of large cross section. The first stage is drilling a diamond-drill hole 3 to 4 in. in diameter in the middle of the pillar to be excavated for the small raise. The second stage is the same as stage 1 in paragraph a on preceding page. The third stage involves the use of the snrinkage method as described in paragraph 3-65b above. The upper raise serves as one manway and the second manway is a crib raise placed in one corner of the shaft. The raise is extended before each blast and covered with bulkhead. The fourth stage consists of placing the supports and lining from the surface, miners meanwhile working on the muck pile.

Equipment used is the same as in paragraph b above, and a hoist is placed at surface or on the level above.

e. Shrinkage. This method is only adaptable for shaft raises of large cross section. First stage: the shaft is excavated full size using the shrinkage method (see paragraph 3-65b). Small cribbed raises are placed in two diagonally opposite corners. Cribbing is added on top of each raise before blasting. The raises serve as two entries to the excavation. Second stage consists of placing support and lining as described in stage 4, paragraph d above.

Equipment used is the same as described in paragraph d above (for details on shaft raise see [26, p 7-12] and [30, p 78].

METHODS AND EQUIPMENT FOR SINKING INCLINES

3-73 GENERAL. The methods used in sinking inclines fall under three distinct types depending upon grade of incline.

a. Type 1 (0 to 15 Percent Grade). Methods and equipment are the same as described in paragraphs 3-57 through 3-60, except that pumping equipment is necessary (for details see [30, p 171]. The simplest pumping arrangement is a sump pump which pumps the water from the heading to a settling sump, 100 to 1000 ft back from the face. The clear water from the settling sump is pumped to the surface.

Support and lining are the same as described in paragraphs 3-50, 3-51, and 3-52. Advantages of inclines from 0 to 15 percent are: (1) people can walk down the incline more readily in emergency; (2) in mass excavation trucks and trackless equipment can be used. (For discussion of inclines versus vertical shafts, see [9, p 7]; for details on bucket dump for sinking inclines, see [26, p 12-95].)

b. Type 2 (15 to 30 Percent Grade). Methods and equipment are the same as described above, except that a hoist is placed at the top of the incline, and the muck car, materials, and equipment are moved in the incline by the hoist.

Mucking is done by the up-and-over type of mucking machine weighted down on the back end. Traction is secured by the use of special cables. The dipper is designed so that it will dig and clean the bottom of the incline the same as the standard dipper cleans the bottom of a horizontal tunnel.

Two- or three-drum standard slushers are also used successfully in inclines of this type. The muck is scraped back from the heading and up an inclined ramp and dumped into the car. The loaded car is pulled up the incline and dumped, as shown in figure 3.27.

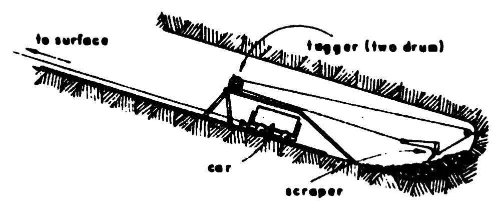


Figure 3.27. Incline showing slusher, ramp, car, and hoist

c. Type 3 (Grade Steeper than 30 Percent). Methods and equipment are the same as described in METHODS AND EQUIPMENT FOR SINKING VERTICALLY,

paragraphs 3-69 and 3-70, except for the following modifications:

(1) The skip is operated on rails.

(2) The timber or steel sets are lined up to grade instead of plumbed as in a vertical shaft.

Disadvantages of inclines steeper than 15 percent are:

(1) Maintenance costs are much greater (approximately 50 to 100 percent).

(2) A much larger cross section (approximately 50 percent) is required for the same operating capacity.

(3) Special equipment or supplies must be rehandled.

3-74 TABULATED COSTS AND NOTES. a. General. Costs given in tables 3.1 and 3.2 are expected to be of comparative value for purposes such as choosing between various sizes of openings. Extraordinary conditions on any particular project may give rise to costs substantially above or below these averages. Costs shown are averages of contract bid prices. They include labor, supplies, equipment rent (or write-off), mobilization, overhead, contingent allowances and profit, but do not include permanent accessories such as permanent track or road surfacing. These costs are based on volumes of work between one-half million and several million dollars and are corrected to 1954 prices.

b. Excavation. Cost figures are based on cross sections shown, without allowance for overbreak or for concrete or other support. If such support is required, additional excavation will usually have to be paid for at rates which will be approximately as shown under cost per cubic yard.

c. Concrete. Costs do not allow for reinforcing except in rectangular shafts in which it is considered that if concrete is used, it should be reinforced. If it is desired to reinforce concrete in tunnels, inclines, or shafts of circular section, cost of concrete may be increased by $9.00 per yd (based on one horizontal and one vertical row of 3/4-in. round rods each on 9-in. centers in a concrete wall of 12-in. minimum thickness at $0.12 per pound of steel furnished and placed). Concrete thickness for small tunnels may be taken as 1 in. per foot of width; actual thicknesses used are:

Size of Tunnel or Incline, ft	Min Thickness of Concrete, in.
8 by 8	8 figured 12
12 by 12	12 figured 16
15 by 15	12 figured 16
17 by 22	15 figured 19
31 by 22	24 figured 28
50 by 50	36 figured 40

It was assumed that overbreak would amount to 4 in. on all tunnels. Where concrete is used, additional excavation should be figured if nominal cross section is to be maintained.

d. Steel Arches. Arches are figured at 5-ft center-to-center spacing of the following steel:

Size of Tunnel or Incline, ft	Steel Section
8 by 8	6-in. WF at 15.5 lb/ft
12 by 12	6-in. WF at 25 lb/ft
15 by 15	8-in. WF at 40 lb/ft
17 by 22	8-in. WF at 58 lb/ft
31 by 22	10-in. WF at 72 lb/ft
50 by 50	14-in. WF at 111 lb/ft

Lighter sections could be used in favorable circumstances. No extra excavation has been shown in this table for room required by steel or lagging. Cost of steel arches is made up of approximately 50 percent for delivered material and 50 percent labor for installing.

e. Lagging. Cost assumes 60 percent of area is covered with 2-in. plank.

f. Tunnel Cross Section (Applies Also to Inclines). Volume of excavation is figured with a flattened arch roof, rectangular invert without allowance for concrete, steel, or unintentional overbreak.

g. Vertical Shafts. Costs are figured with steel sets (buntons in the circular shaft) with landings and ladders. Excavation in the rectangular shaft is figured with 6 in. for blocking and overbreak, and in the circular shaft for 6 in. of concrete plus 4 in. overbreak. Both shafts will always require steel or timber sets and ladders; circular shafts will usually require concrete. If rectangular shafts are concreted, the concrete should be reinforced. Prices shown include rent of sinking hoists

and head frames, but do not include costs of permanent equipment which may be more elaborate.

h. Raises. Raises more than 50 ft high or steeper than 50° from horizontal require timber (usually by state or other requirements) and this cost is included.

i. High Chambers. Costs will vary depending on the amount of work to be done, the methods, the equipment chosen, and the organization of the work. Limits shown assume no support, and should apply for benching, shrinkage, or sublevel mining.

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